CHARACTERISATION OF 11KV FAULT LEVEL CONTRIBUTIONS BASED ON SUBSTATION LOAD PROFILE

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ABSTRACT

This paper discusses the development and application of MVA per MVA general load infeed templates for 11kV distribution network modelling based on the Primary substation load profile. This paper is based on learning from Western Power Distribution's (WPD) Tier-2 Low Carbon Networks Fund project, FlexDGrid [1].

INTRODUCTION

In order to meet targets for carbon emission reductions associated with energy production both globally and in the UK, the installation and connection of Distributed Generation (DG) onto the distribution network has significantly increased. The connection of DG units provides low-carbon energy, however these units also contribute to the fault level of the network.

To establish the most suitable network connection point, modelling of the network and new generation is carried out using power system analysis software. The accuracy of the distribution network model is paramount in determining the change in fault level attributable to a new DG connection. DG is modelled using generator-specific details in relation to sub-transient, transient and steady-state conditions; however, the general load contribution to fault level is commonly modelled through one of two pre-evaluated contributions as determined in G74 [2].

This paper builds on findings previously reported [3], describing the process used for determining substation-connected load types, the development of the 11kV general load infeed template and the application of the template at another substation. The aim of this learning is to investigate whether monitored real-time fault level values from a selection of substations can be used to provide greater fault level calculation accuracy at a non-monitored substation.

BACKGROUND

Historically, there has been a desire to operate the distribution network with a large fault level to assist in the rapid operation of protection systems and to suppress the effect of motor start. With the increased penetration of DG in the distribution network at all voltage levels, but especially at 11kV, fault level issues are becoming a significant barrier to connection.

Fault levels are most commonly modelled using power system analysis tools. While generators are modelled using their specific electrical characteristics, the vast and varying types of load connected to the network has meant a generic modelling approach has been considered to date. Guidance is given in documentation such as G74 as to the values to be applied; however this is typically split by voltage level.

Section 9.5.1 of G74 states: for low-voltage networks allow 1.0 MVA per MVA of aggregate low-voltage network substation winter demand and for high-voltage connected load 2.6 MVA. These values are applied to the substation load as a whole and are irrespective of load type. An overview is provided in Figure 1 below showing the different contributions to the overall fault level at a given point on the network, in this case, the 11kV substation.

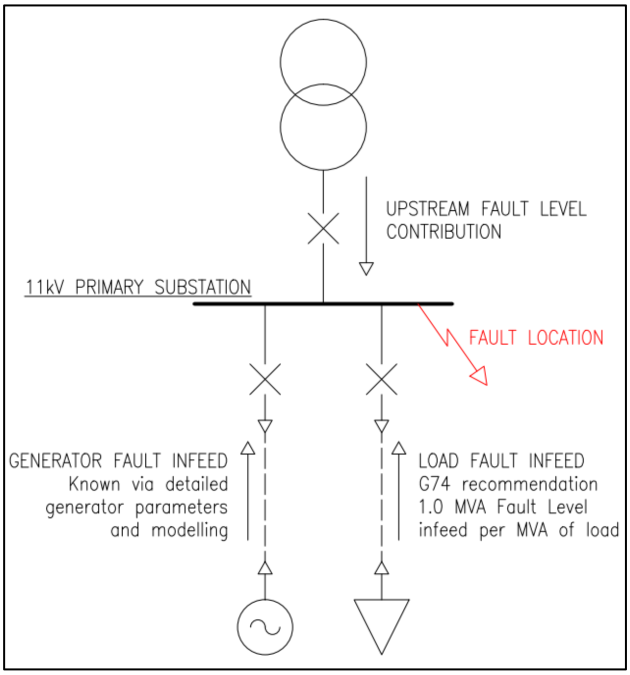

Figure 1 – Overview of Fault Level Contributions

As technology progresses with the ability to gather more sophisticated network data, such as real-time fault level values along with a greater understanding of connected load types, there is an opportunity to further understand the contribution of general load to the overall fault level.

ENHANCED NETWORK MODELLING

A primary aim of FlexDGrid Method Alpha was to develop an Enhanced Fault Level Assessment (EFLA) process for the 11kV network. Using available network data sources, the primary networks for each substation within the project area were added to the existing 11kV network models currently used by system planners when assessing generation connections.

By using customer metering data and the agreed supply capacity, the size of each load connected to the 11kV network was estimated. A distribution factor was then applied to each so that the total load at the primary substation was equal to the winter maximum demand as per current WPD planning policy.

FAULT LEVEL MONITORING

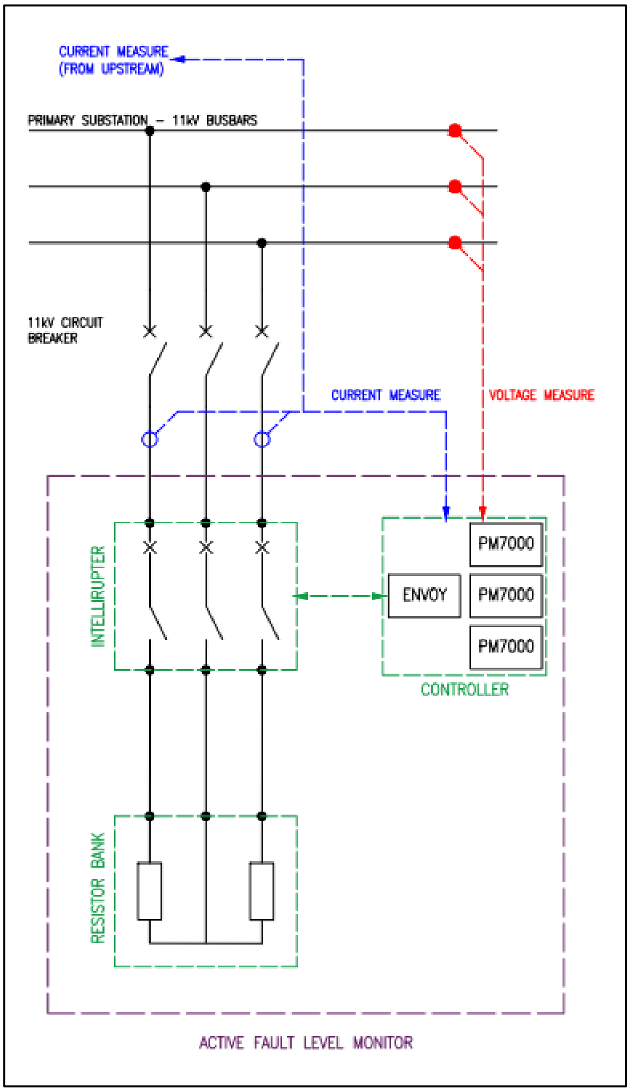

Figure 2: Single-Line Diagram of AFLM

The aim of FlexDGrid Method Beta was to install and safely operate ten Active Fault Level Monitor (AFLM) devices throughout the project area. The AFLM is designed to place a non-customer-affecting disturbance on the 11kV network with monitoring hardware within the device recording the waveform disturbances for both current and voltage [4].

Installation and open-loop testing of the devices was completed in 2015 [5] with the transition to closed-loop operation for all the devices undertaken during 2016. The majority of the sites continue to automatically operate every six hours with two sites set to operate every three hours. As part of the transition to closed-loop operation, a facility has been built into each device allowing a remote command to be issued, instigating an AFLM operation.

Using the disturbances created by the AFLM, the device is able to calculate the 10ms peak fault level and the 90ms RMS fault level at the point of connection. Figure 2 shows the single-line diagram of the AFLM device connected to an 11kV busbar. Through the positioning of current monitoring points on the feeder to the AFLM device and the upstream source feeder, the device has the ability to distinguish between the fault level contribution from the upstream network, through the primary transformer, and the contribution from the 11kV network with the AFLM device connected to it.

MVA PER MVA TEMPLATE

In order to calculate the MVA per MVA infeed value for each FlexDGrid substation, the ELFA models were utilised.

To create an 11kV MVA per MVA infeed template for different loads, two factors were considered; the 11kV Fault Level contribution value generated by the AFLM and the substation load profile. The data was used in conjunction with the ELFA tools to determine the MVA per MVA infeed value for that instance in time.

11kV Fault Contribution

The fault level data collected by the AFLM, along with standard network configuration information and operating data, were used to manipulate the model to match the actual network conditions as close as reasonably practicable. Minor modifications were made to the scripts behind the ELFA tool to manipulate the MVA per MVA infeed value used by the G74 fault calculation until the modelled fault level closely matched the recorded value from the substation.

In order to generate a generic, user-friendly template that can be applied at any substation, the MVA per MVA infeed values calculated at each time point were averaged. Table 1 below shows the average MVA per MVA value calculated at each FlexDGrid substation.

Substation	Average MVA/MVA
BARG	0.9
BOVI	1.0
CASB	6.0
CHAV	0.8
CHES	5.5
ELMD	2.8
HALG	1.3
KITG	4.2
NECW	5.8
SHIR	3.5

Table 1 - Average Fault Infeed at FlexDGrid Substations

Substation Load Profile

To determine the size of various load types connected to a particular substation, annual metering data from 2014 was analysed and split into three categories: Domestic, Small Industrial/Commercial and Large Industrial/ Commercial. Using individual feeder and customer metering data where available, the load breakdown for the network with the AFLM device connected was refined, as shown in Table 2 below.

Substation	% Demand on AFLM Network		
	Domestic	Small Com/Ind	Large Com/Ind
BARG	67%	20%	14%
BOVI	63%	14%	23%
CASB	24%	10%	66%
CHAV	80%	11%	9%
CHES	20%	19%	61%
ELMD	7%	7%	86%
HALG	73%	19%	7%
KITG	44%	14%	42%
NECW	35%	24%	41%
SHIR	51%	25%	23%

Table 2 - 11kV Substation Demand by Load Type

Template

The data was combined and, based on the percentage of domestic demand at the substation, the graph in Figure 3 was generated. The AFLM device has a tested accuracy of 5% on calculated peak fault levels. Due to the fact that the upstream fault level contribution could not be tested in the laboratory, it was decided that the results would be grouped to provide a recommendation for the MVA per MVA infeed value based on general load type.

The results show that the substations with a relatively large domestic load have a low MVA per MVA 11kV infeed of around 1.0, as per G74. However, as the percentage of industrial load connected increases it was seen that the MVA per MVA infeed recorded increased.

It was found that ELMD substation, with a majority Large Industrial/Commercial load, had an average MVA/MVA infeed of 3.2. Further analysis of the network showed that the typical loads connected to the network were from commercial rather than industrial customers. This means that there is a reduction in the number of motors connected to the network leading to a reduction in the 11kV fault level contribution. Table 3 shows the proposed MVA per MVA 11kV load infeed values for different general load characteristics

Load	G74 MVA per MVA Infeed
Majority Domestic	1.0
Split Domestic/Industrial	3.0
Majority Commercial	3.0
Majority Industrial	5.0

Table 3 - Proposed MVA per MVA Infeed values based on Load

APPLICATION OF TEMPLATE

To test the MVA per MVA infeed template that had been developed, another substation within the geographical trial area was selected. The selected substation load make-up is shown in Table 4 below.

Substation	Domestic	Small Com/Ind	Large Com/Ind
LADW	15%	20%	65%

Table 4 – Load breakdown at trial substation

Analysis of the Large Commercial/Industrial load showed that the majority was made up of commercial customers. This means that the substation has a similar load make-up to ELMD. Therefore an MVA per MVA infeed value of 3.0 was selected. Using the ELFA process, the fault level was calculated using this new FlexDGrid value and the existing G74 value. Table 5 below provides a summary of the results gathered and compares them to the total Fault Level and MVA per MVA results from an AFLM device installed on the site.

	MVA/MVA	11kV Fault Level
EFLA - G74	1.0	19.4 kA
EFLA - FlexDGrid	3.0	23.4 kA
AFLM	2.7	21.5 kA

Table 5 – Fault Level results from template application at trial substation.

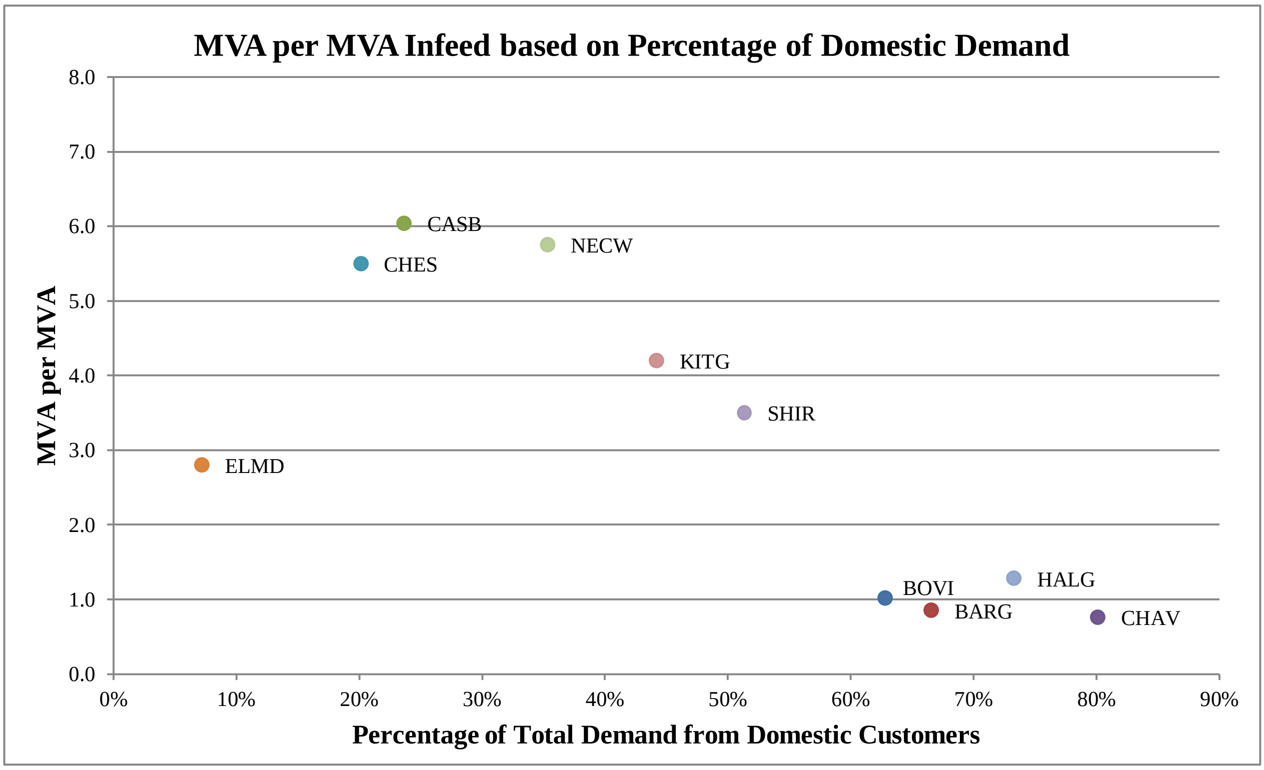

Figure 3 - MVA per MVA Load Infeed based on % of Domestic Demand at each Substation

Comparing the results breakdown from the AFLM and ELFA process it was noted that there was a discrepancy between the upstream fault level contributions with the AFLM device recording a value 1kA lower. This explains the majority of the difference between the AFLM results and the ELFA results using the FlexDGrid recommended MVA per MVA value.

LEARNING

The results produced by all AFLM devices show that the 1.0 MVA per MVA general load infeed value at 11kV is no longer valid for all substation loads. Further work and recordings are required over a greater range of substations to come to a definitive conclusion of fault contribution per load type. In order for this to occur, the AFLM device requires further development to reduce the overall space requirements and to simplify the installation requirements.

During the operation of the device, though not validated by laboratory tests, it was witnessed that the upstream Fault Level infeed determined by the AFLM device was typically lower than modelled values. This suggests that current models, for the FlexDGrid trial area, are over-estimating the fault level infeed from the 132kV network and underestimating the infeed from the 11kV network.

The AFLM technology was in development throughout the project and in testing was proved to calculate total fault levels to ±5% accuracy. For calculating the MVA per MVA, greater accuracy of the recording equipment is required to come to a definitive conclusion.

REFERENCES

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